# ARMORED
# MEDICAL RESEARCH LABORATORY
## FORT KNOX, KENTUCKY

PROJECT NO. 2 - OPERATIONS AT HIGH TEMPERATURES

First Partial Report

On

Sub-Project No. 2-24, Study of Methods of Reducing the Heat Load
in Tanks

Project No. 2-24                    INFORMATION COPY                    11 May 1943

ARMORED FORCE MEDICAL RESEARCH LABORATORY
Fort Knox, Kentucky

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1. PROJECT: No. 2 - Operations at High Temperatures. First
partial report on: Sub-Project No. 2-24 - Study of Methods of Re-
ducing the Heat Load in Tanks.

    a. Authority - Letter Commanding General, Headquarters Armored
Force, Fort Knox, Kentucky, 400.112/6 GNOHD, dated September 24, 1942.

    b. Purpose - To investigate the value of heat-reflecting paint
on the exterior surfaces of tanks as a means of reducing the solar heat
load.

2. DISCUSSION:

    a. General -

        (1) Absorption of solar heat by a tank raises the inside
air and wall temperatures appreciably and thus increases the heat load
to which the crew is exposed.

        (2) The degree to which the air temperature within the
tank increases depends upon several factors, including the following:

            (a) Percentage of solar energy absorbed by the vehicle.

            (b) Rate of heat transmission through the tank walls.

            (c) Rate of ventilation.

        (3) These factors are subject to some control; the rate of
heat transfer through the walls can be reduced by insulation; the rate of
heat removal can be increased by increasing the ventilation and the per-
centage of solar radiation which is absorbed can be reduced by proper
selection of paint for the exterior surface of the vehicle.

3. CONCLUSIONS:

    a. Solar radiation constitutes an important source of heat in
tanks and other closed vehicles when exposed to the sun.

    b. The amount of heat absorbed is sufficient to increase the air
temperature 20°F or more above outside temperature within a buttoned-up
tank with minimum ventilation (engine idling).

c. The standard O.D. paint now employed absorbs approximately 90% of the solar radiation received.

        d. Absorption of solar heat can be reduced by painting the exterior surfaces with an infra-red reflecting paint, which will approximate present paint so far as color and visibility to the eye are concerned but which, at the same time, will reflect a high percentage of solar energy in the infra-red region.

        e. Even greater reduction in solar heat absorption can be secured by using a paint with the highest permissible reflection in the zone of visible light, as well as maximum infra-red reflectance.

    4. RECOMMENDATION:

        That a paint for exterior surfaces of tanks be developed to give the maximum possible reflection of solar energy, consistent with the require - ments for concealment.

Submitted by:

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6 Inclosures
    #1 - Appendix with tables
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    #2 - Fig. 1
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# APPENDIX

## SOLAR HEAT ABSORPTION BY TANKS

Radiant energy from the sun varies in wave length from the ultra-violet through the region of visible light into the infra-red zone. All of the solar energy absorbed by a receiving body, however, is converted to heat.

On a clear day in the tropics with the sun directly overhead the solar heat received at sea level reaches a maximum of 332 Btu per hour per sq. ft. of surface normal to the sun. The intensity of radiation varies with the distance of atmospheric penetration and therefore with elevation of the sun and with altitude. The effect of the latter is to add approximately 10 Btu per sq. ft. per hour to the sea level value for every 1000 ft. elevation. The variation with height of the sun is in direct proportion to the sine of the angle of elevation. In round numbers, the maximum daily intensity of solar radiation may be taken as 300 Btu per sq. ft. per hour. Lesser values will be found on cloudy or hazy days. The diurnal variation for a midsummer day in the latitude of Washington is shown in Fig. I. Total energy received by a horizontal surface during the entire day amounts to approximately 2200 Btu per sq. ft. of horizontal surface. Thus, the heat received by a medium tank would be sufficient, if none were lost, to raise the temperature of the entire vehicle more than $40^\circ$F. At midday, the solar heat received by the shadow area of the crew compartment* amounts to about 24,000 Btu per hour. Assuming a rate of ventilation through the tank of 500 cfm and also that one-half of the absorbed heat is transmitted to the inside, the temperature rise of the air flowing through the tank would be $20^\circ$F.

Some actual tank temperatures are given in Table 1. It will be noted that the observed values for buttoned-up tanks, with the engine idling, are in close agreement with the foregoing calculated temperature rise. One also notes a marked increase in wall temperatures with corresponding increase in the radiation heat load inside the tank. Accompanying the rise in temperature within the tank there is an increase in the moisture content of the air from the evaporation of sweat, which adds to the discomfort. In Egypt the increase in water vapor in the air of a fully manned tank was found to average 40 grains per pound of dry air. This corresponds approximately to an hourly water loss per man of 1 liter, which is in agreement with the findings on water loss in extreme desert heat. The combined effect of these factors (increase in air and wall temperatures and moisture content) is to raise the effective temperature** to undesirable levels. In Egypt, effective temperatures

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* Assuming 80 sq. ft. of shadow area and intensity of solar radiation of 300 Btu per hour per sq. ft.

** Effective temperature is an arbitrary scale for comparing various combinations of temperature, humidity and air movement in relation to man's relative sensation of warmth. An E.T. of $90^\circ$ is equivalent to a still saturated atmosphere at $90^\circ$F.

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# Table 1

## Turret Temperatures in Buttoned-up Tanks Exposed to Sun

### (Deadlined, Engine Idling and Driving)

| Place | Outside Air Temperature | Tank | | Excess Turret Air Temperature | Inside Turret Wall Temperature | Remarks |
|---|---|---|---|---|---|---|
| | | Model | Operation | | | |
| Ft. Knox | 85° | M3 Med. | Deadlined | 10-18° | 113-130° | 5 hrs. exp. on mod. clear day |
| Ft. Knox | 92-98° | M3 Med. | Deadlined | 7-27° | 128-141° | 5 hrs. exp. on cloudless day |
| Camp Young, California | 104° (Max) | M3 Med. | Deadlined | 25° | 149° Max. | cloudless day |
| Ft. Knox | 85° | M3 Med. | Eng. Idling | 2-25° | 102-122° | 5 hrs. exp. on mod. clear day |
| Egypt | 88° | M3 light | Eng. Idling | 32°* | --- | --- |
| Ft. Knox | 85° | M3 Med. | Driving | Aver. 6° | 85-97° | 100 miles driv. mod. clear day |
| Camp Young, California | 110° | M4A1 | Driving | 5-13° | 130° | cloudless day |
| Egypt | 87-103° | Various | Driving | Aver. 10°* | --- | --- |

\* Temperatures taken at the various crew positions.

Table 1

above 90° were recorded and for moist climates such as in Rangoon, values as high as 100° E.T. have been predicted. This is equivalent to a saturated atmosphere at 100°F, which is intolerable.

The effect of increasing ventilation with high engine speeds and the beneficial influence of motion of the tank are also seen in the data presented in Table 1. The action of the latter is to increase the outward loss of heat absorbed by the tank walls in proportion to the amount transmitted to the inside; this, together with the greater air flow through the tank results in a lower internal temperature rise. In contrast to a 20° rise in a stationary tank with engine idling, an increase of only 5° is experienced under these more favorable conditions.

For a gas-proof tank, the present indications are that a considerably lower rate of ventilation will have to be provided than is now supplied. This situation, together with the fact that tanks must, at times, remain stationary in the open makes it desirable, in the interest of crew efficiency, to reduce the amount of solar heat absorbed by tanks. Among the various means for accomplishing this is to paint the exterior surface of the tank so as to provide the maximum possible reflection of the sun's rays which strike it. Thus, a paint having an overall reflection factor of 50% would reduce the amount of heat absorbed to one-half of that taken up by a completely black surface, with comparable improvement in interior temperatures. The O.D. tank paint now employed has been found to be very little better than black paint in this respect. Compare, for example, the temperature-rise curves in Fig. 2. Curve A shows the temperature rise of a black test panel when exposed to a constant source of radiant energy. Curve B is for a similar panel painted with the standard O.D. paint. The final temperature reached by the latter was only 10% below that of the black plate. In striking contrast, a plate painted with titanium oxide white and exposed under exactly the same conditions exhibited a temperature rise of only 33% of the black plate (Curve C). The difference was due to the high coefficient of reflection of the white surface. In the same way, an olive drab paint having high reflectance in the infra-red was found to reduce heat absorption about 2/3 (Curve D). The source of radiation in these tests was a tungsten lamp which was relatively richer in infra-red than the sun. Hence, the results with the IR olive drab paint are more favorable than would be obtained under solar radiation.

The comparative benefits to be obtained by various types and colors of paints are also shown in Table 2, which gives the equilibrium temperatures for a series of cans of gasoline painted in different colors and exposed to sunlight in Florida. One notes a marked difference between the temperatures within the can painted flat white and the one painted medium gray. Other colors gave intermediate readings. The lower temperature obtained with flat white paint resulted from its high-reflectance. This very feature, however, makes white an unacceptable color for a tank because of its high visibility. To be acceptable, the paint used must possess a sufficiently high reflectance of total solar energy to give useful results without exceeding the maximum permissible reflectance of light in the visible region. Paints designed with this

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Incl. 1

Table 2

Effect of Paint Reflectance Upon the Temperature of Gasoline
in Cans Exposed to the Sun*

| Paint | Gasoline Temperature $^\circ$F |
|---|---|
| Flat White | 82 |
| Gloss White | 84 |
| Aluminum | 87 |
| Chrome Yellow | 90 |
| Lab. Olive I.R. | 95 |
| Chrome Oxide No. 1 | 96 |
| Com. Brown I.R. | 96 |
| Com. Green I.R. | 96 |
| Com. Green I.R. | 97 |
| Com. Gray I.R. | 98 |
| Med. Gray | 99 |

* Infra-red Reflectance versus Evaporation, H. A. Gardner, Circular
No. 636, Sci. Sec., Nat'l. Paint, Varnish and Lacquer Assn., Inc.,
Washington, Mar., 1942.

Table 2

Incl. 1

objective in view are now available. They are formulated to meet the necessary specifications as to color brightness in the zone of visible light but at the same time to have the highest possible coefficient of reflection throughout the region of invisible infra-red rays. They are generally termed IR or infray paints.

In the development of these paints advantage is taken of the fact that a considerable proportion of the energy received from the sun lies beyond the invisible region, i.e. wave lengths longer than $0.76\mu$. The degree of reflection or absorption of this invisible energy does not affect the appearance of the painted surface in visible light and from the standpoint of camouflage it is said to be desirable to reflect a high proportion of the infra-red energy in order more nearly to simulate the background of vegetation.

The spectral distribution of solar energy as received at sea level on an average midsummer day at Washington, D. C., is shown in Fig. 3*. Maximum intensity of radiation occurs in the visible region. It rises very sharply from the minute percentage in the ultra violet and decreases more gradually in the infra-red. The distribution of energy between the visible and infra-red is, according to this curve, in the ratio of 55:45; that is, rather more than half of the total lies within the region of visible light.

In Fig. 4, the reflectance curve for a high I.R. reflecting paint has been plotted in conjunction with the approximate solar energy distribution curve. The products of the reflectance and the corresponding solar energy values for various wave lengths are also plotted in the Figure. The area under this curve (cross-hatched) represents the total amount of solar energy reflected by the paint while the area between the $R_s$ and I curves represents the amount absorbed. For the paint in question, the heat absorption, as compared with that taken up by a perfect black surface, is only 56%.

A reduction in solar heat gain of the order exhibited by the IR paint in Fig. 4 will result in a definite improvement in tank temperatures, as shown in Fig. 5. The three sets of temperatures were obtained under the same condition with respect to outside air temperature and wind velocity. The radiant heat load differed in the tests, however, by factors of 1.0, 0.8, and 0.6; that is, in test 2 the amount of radiant heat absorbed was reduced 20% as compared with test 1 while in test 3 the reduction was 40%. There was a relative improvement in turret temperatures after 1000 hours, resulting in maximum temperatures $9°F$ and $18°F$ lower in the two tests with reduced radiant heat than when the tank was exposed to the full radiation load. These were laboratory tests in which the source of radiant energy was directly controlled. They do not represent actual results obtained with heat-reflecting paints but were conducted to show the magnitude of the benefit to be derived from paints giving the same reduction in solar radiation. The results are in close agreement with the comparative findings in two test chambers exposed to sunlight,

* Measurement and application of visible and near-visible Radiation, F. S. Brackett, Biological Effects of Radiation, McGraw-Hill Book Co., Inc., New York.

the roof of one being coated with an IR paint somewhat similar to that shown in Fig. 4 and the other with an ordinary paint of the same color and visibility. The effect of the IR paint was to reduce the total accumulation of heat during a day by approximately 33%. The difference in maximum temperatures in the two chambers was 12°F.

The characteristic feature of an IR paint is that it has relatively high reflectance in the infra-red region. Its behavior in the zone of visible light is determined by requirements for concealment. For low visibility, low reflectance in the visible region is essential. The IR paint shown in Fig. 4 possesses this characteristic, with a rapid rise in reflectivity with increasing wave length above 0.76 $\mu$.

So long as low visibility must be maintained, the maximum percentage reduction in solar heat absorption which can be secured by a paint is limited since so large a proportion of the solar energy lies in the visible region-- up to 60%. It is clear that the heat reflecting properties of a paint can be greatly improved if a higher reflectance is permitted in the region of visible light. The benefits to be gained thereby are shown in a striking manner by the following temperature records taken in gasoline storage tanks over a period of three (3) months.

## Table 3

### Temperatures of Stored Gasoline in Relation to Reflectance in Visible and Infra-Red Zones*

| Paint | Aver. Excess Temp. over Air Temp. °F |
|---|---|
| White | 1.0 |
| Aluminum | 6.7 |
| I.R. Olive Drab, Specification #9 | 9.0 |
| Std. Olive Drab, Specification #9 | 13.7 |

The use of the I.R. olive drab paint reduced the excess temperature to a significant degree as compared with the standard O.D. but a much greater effect was noted with the aluminum and white paints which also had high reflectance in the visible region. It is not suggested that white paint be employed on tanks. It is recommended, however, that, in the selection of paint for tanks, consideration be given to the heat-reflecting properties as well as the camouflage requirements and that, so far as possible, maximum use be made of reflection in the zone of visible as well as the infrared radiation. It is not within the scope of this report to consider camouflage requirements but the question is raised as to the actual need for a paint of extremely low visible light reflection. To what extent can visible reflection be increased without destroying essential hiding power, especially in arid open country?

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* Courtesy Capt. Metz, Ord. Dept.

Incl. 1

FIG. I

SOLAR RADIATION RECEIVED ON A HORIZONTAL SURFACE
DURING AVERAGE MIDSUMMER DAY, WASHINGTON, D. C.
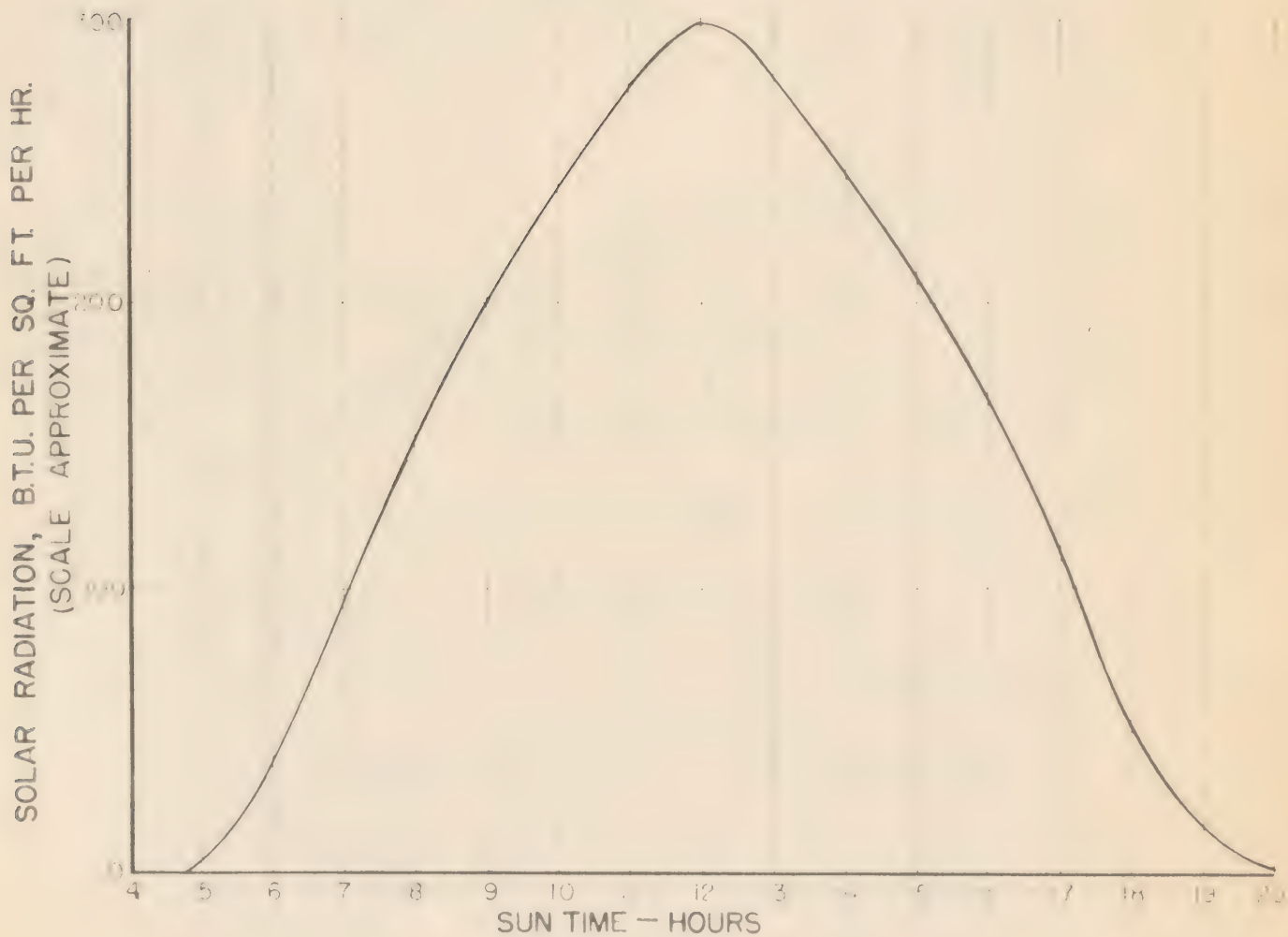
FIG. 2

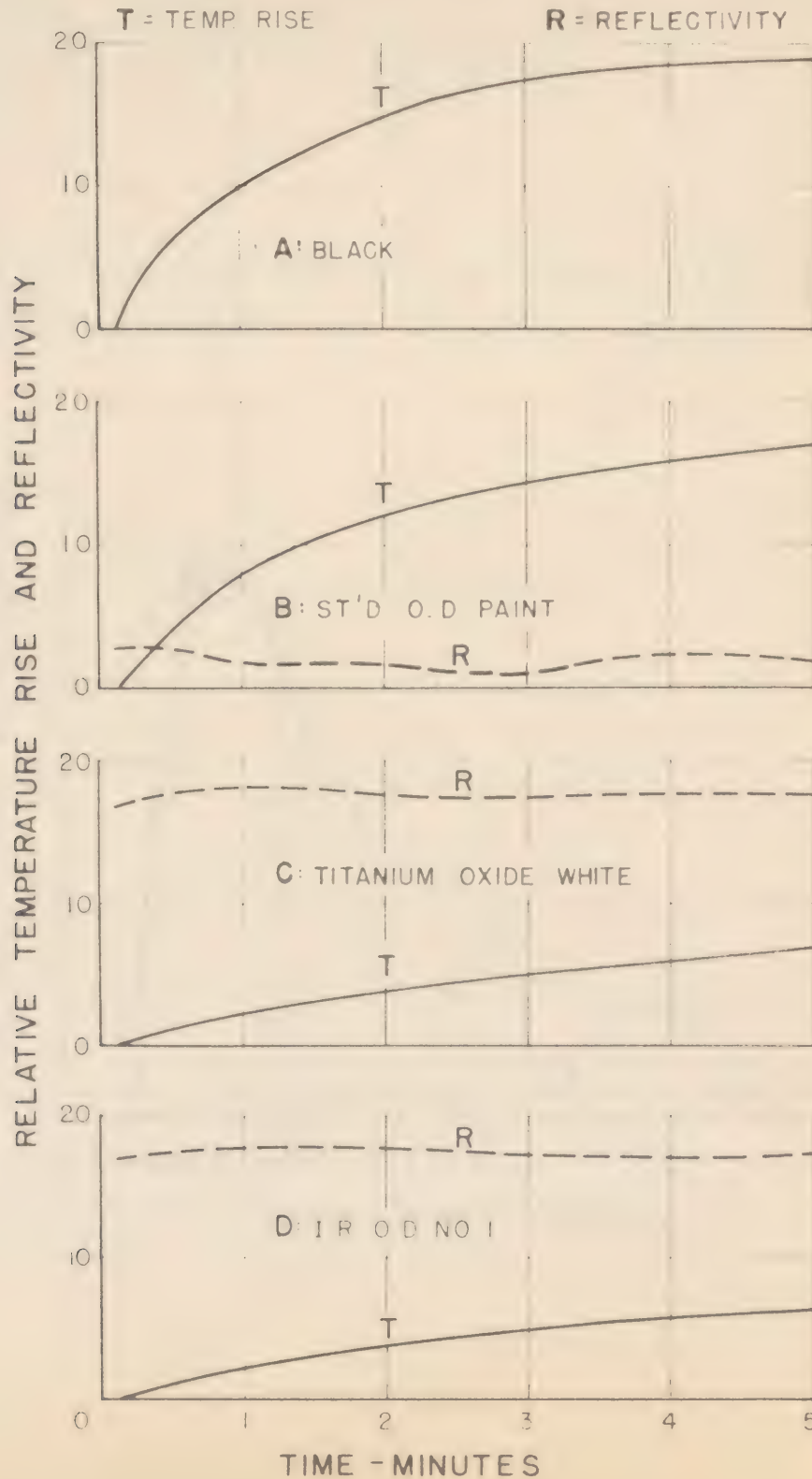EFFECT OF PAINT UPON TEMPERATURE RISE OF TEST PLATES
EXPOSED TO CONSTANT RADIATION

FIG. 2

# FIG. 3

## SPECTRAL DISTRIBUTION OF SOLAR RADIATION
## AVERAGE MIDSUMMER DAY AT NOON, WASHINGTON, D.C.
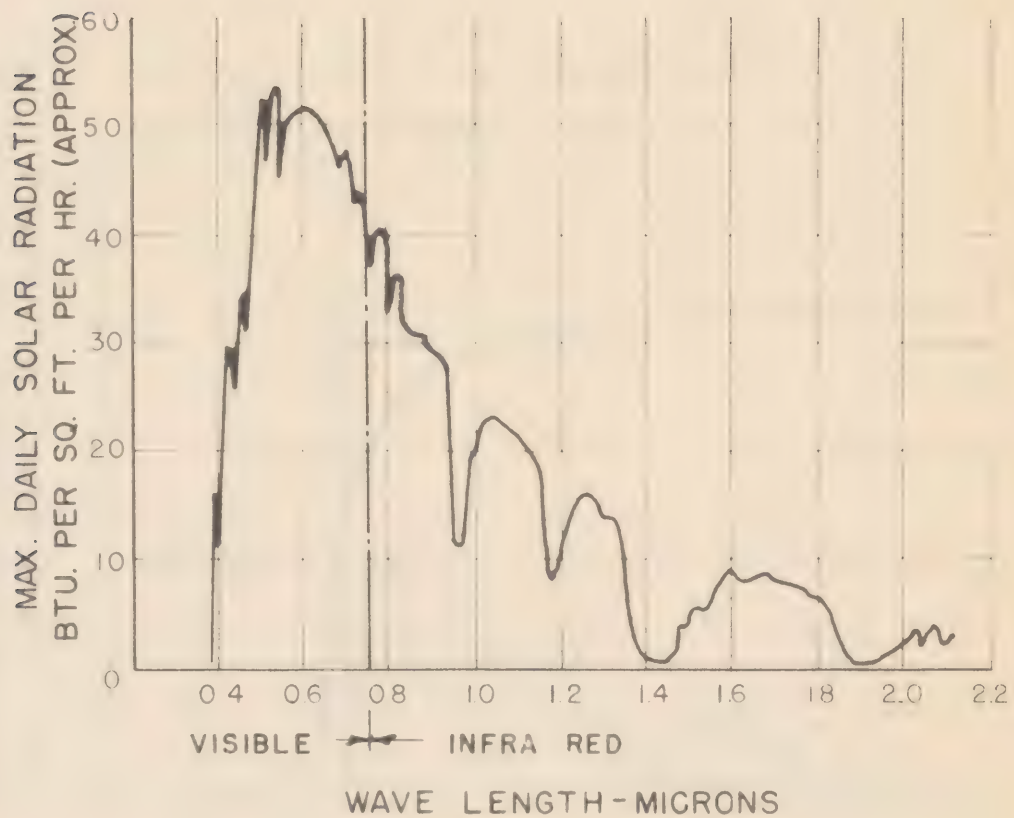


VISIBLE — INFRA RED

WAVE LENGTH – MICRONS

FIG. 3

# Fig. 4

DISTRIBUTION OF SOLAR ENERGY, I (0.1μ INCREMENTS)
REFLECTIVITY OF AN I.R. PAINT, $R_P$, PERCENT
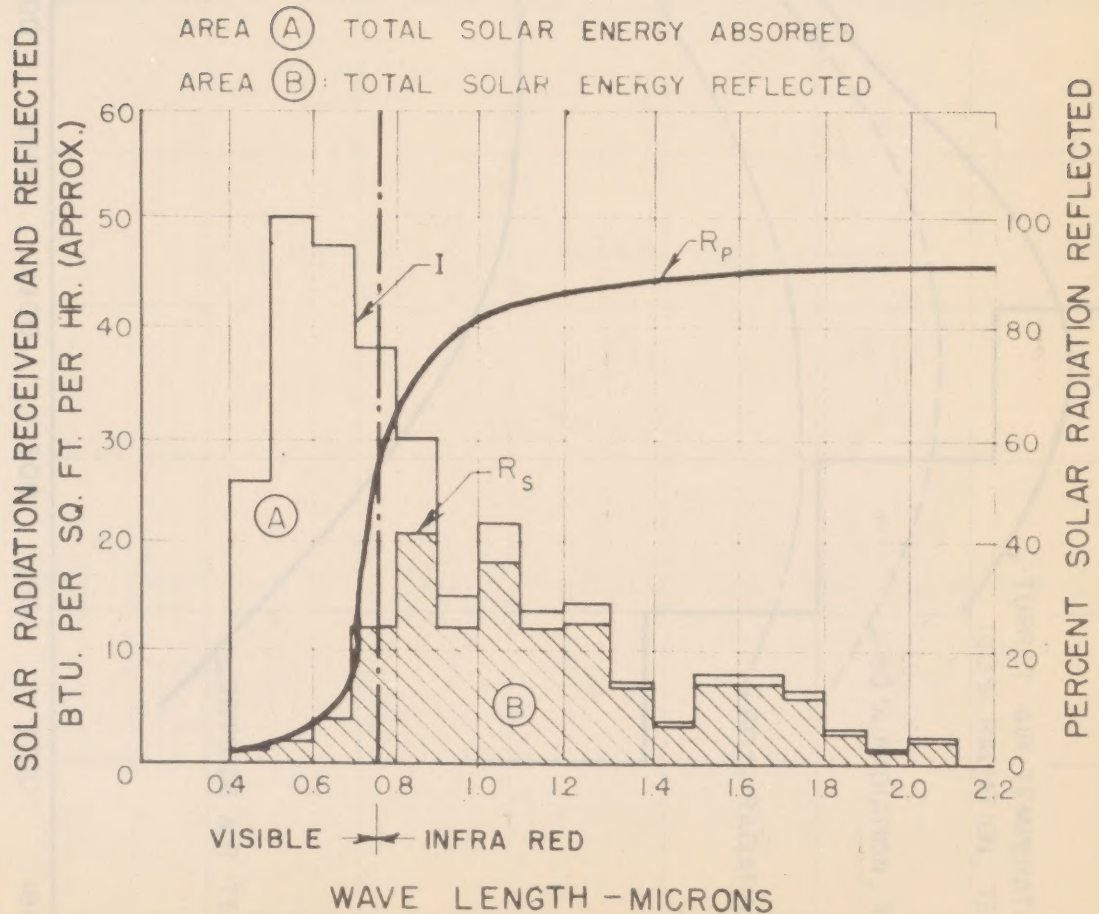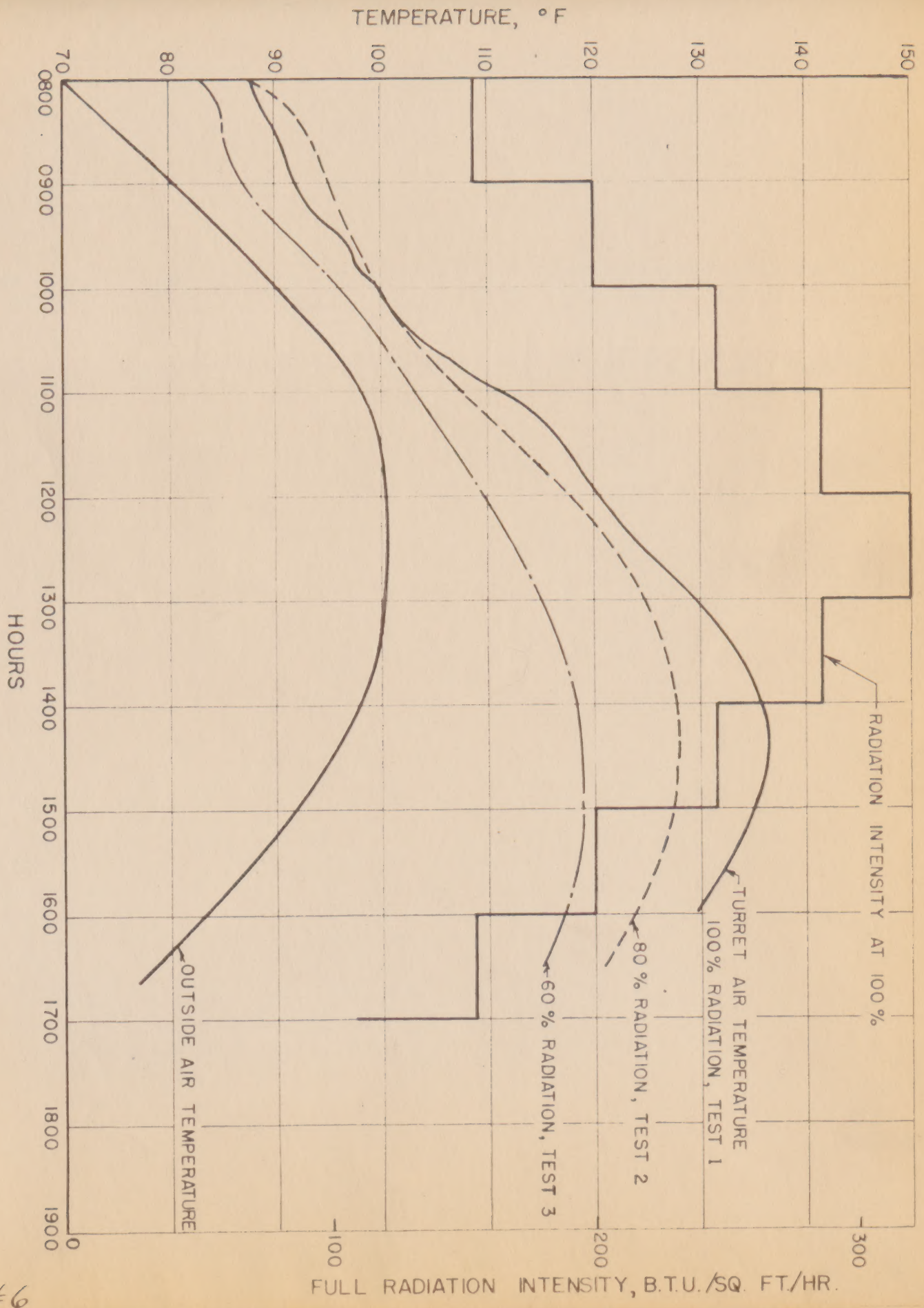SOLAR ENERGY REFLECTED (PRODUCT I x $R_P$), $R_S$



FIG. 4

EFFECT OF RADIATION LOAD UPON TURRET AIR TEMPERATURE

FIG. 5

Incl. #6

RADIATION IN 40°K.

RADIATION IN INTENSITY WITH ½ 40°K

TURRET AIR TEMPERATURE
100% RADIATION, TEST 1
50% RADIATION, TEST 2
80° RADIATION, TEST 2
90° RADIATION, TEST 2

OUTSIDE AIR TEMPERATURE

EFFECT OF RADIATION LOAD UPON TURRET AIR TEMPERATURE

FIG. 5

HOURS

TEMPERATURE °F.